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A HYDRAULICALLY ACTUATED TEST FRAME FOR THE FIELD DETERMINATION OF ICE FLEXURAL PROPERTIES

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A HYDRAULICALLY ACTUATED TEST FRAME FOR THE FIELD DETERMINATION OF ICE FLEXURAL PROPERTIES[1]

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ABSTRACT

The resistance to downstream forces by a typical river-ice sheet is controlled primarily by its thickness, internal strength and compliance, and the retention mechanisms at work transferring those forces to the bank and bed. Flexural loading is one of the dominant mechanisms promoting failure at the ice-bank/bed interfaces and at the breakup front and plays a significant role in determining the rate of ice cover clearance. As part of an on-going series of investigations into the mechanical processes important to the evolution and progression of breakup, this paper reports on the development and field application of a device used to measure the flexural properties of ice during the period preceding breakup.

INTRODUCTION

Although numerous investigators have presented techniques and the results of investigations concerning flexural properties of fresh water ice (see for example Bulatov, 1970; Frankenstein, 1961; Gow and Langston, 1975; Gow, et al. 1988; Timco and Frederking, 1982), most have focused on cold ice (ie.<0°C) but largely neglected specific details about the thermal condition of the ice or the hydro-meteorological conditions that led to the observed ice structure. More importantly there is a dearth of studies dealing with the flexural properties associated with ice after it has reached the melting point and begun to alter structurally from radiation decay. As part of an overall study (see Prowse et al. 1988; Demuth and Prowse, 1988) which encompasses the in situ measurement of decreases in ice strength and strain modulus, detailed radiation/energy balance and ice morphology experiments have been run concurrently at a small lake near the National Hydrology Research Institute in Saskatoon. Analysis of the data (not presented here in detail) will focus on the determination of representative flexural properties for radiation-decayed 0°C ice. The variation of these properties are being analyzed along with data from the energy balance and ice morphology determinations.

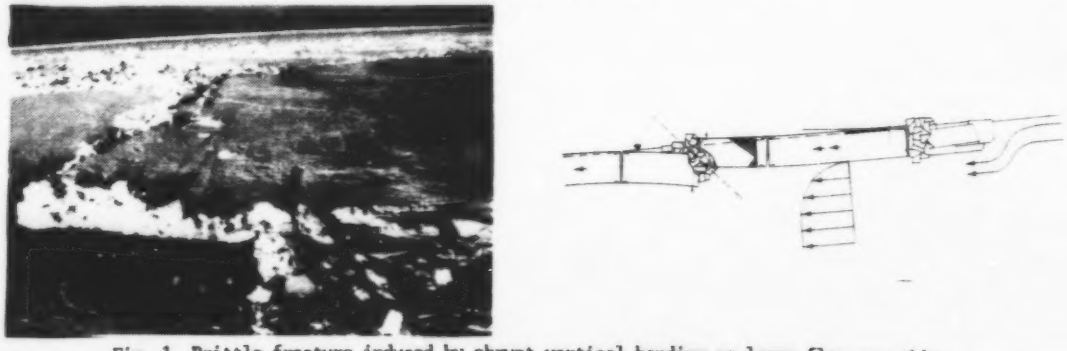

Fig. 1 Brittle fracture induced by abrupt vertical bending as large floe overrides intact ice. Flow is from right to left (Mackenzie River at Fort Simpson, N.W.T., May, 1988).

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EXPERIMENTAL METHODOLOGY AND INSTRUMENTATION

The primary role of the loading device was to permit periodic in situ measurements of flexural strength and strain modulus as the ice became increasingly decayed by radiation. The flexural loading design is based on the simple support of an ice beam specimen, using a rigid frame to carry the reactions produced by a three/four point bending test (Fig. 2). This design aspect is important when testing highly decayed ice covers as the imparting of reaction forces to the parent ice sheet may induce excessive deflection and/or localized failure.

In general, beams are cut and maneuvered to the test frame suspended in a slot cut in the parent ice sheet (Fig. 3). Load is applied through a hydraulic actuator which is integral to the reaction frame. The support span is adjustable from 2.25 m to 1.25 m at 0.25 m intervals. Accommodation of beam depth is continuously adjustable, with a maximum of 0.9 m.

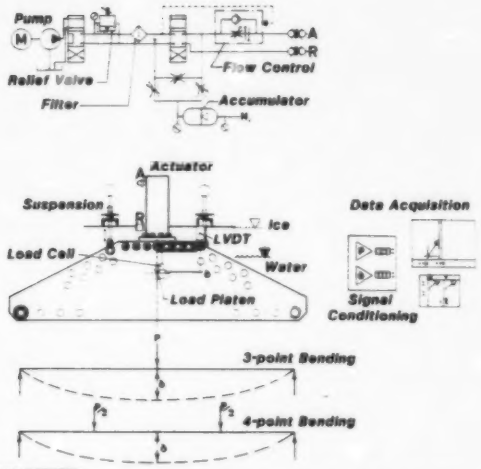

Fig. 2 Test frame schematic illustrating the hydraulic system and the loading geometry imposed on the beam specimen.

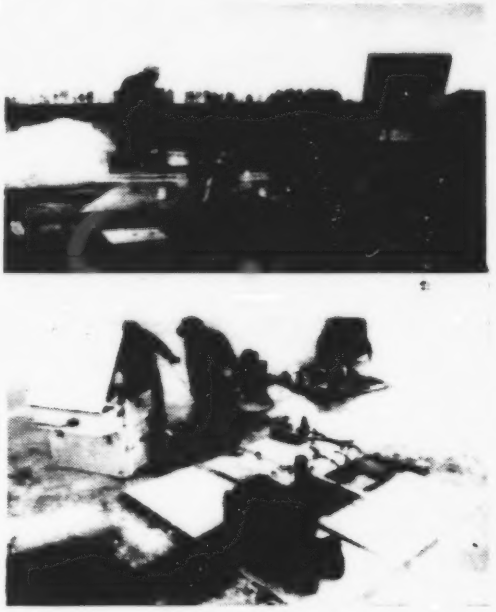

Fig. 3 Test frame installed in situ at Floral Pond.

Hydraulic fluid pressure is supplied by a portable pump rated at 0.37 kW providing oil pressures in the range of 0 - 69x10^3 kPa with corresponding oil flows of 3.7 L min^{-1} to 0.3 L min^{-1}. Fluid filtration is provided by a 3-μm, pressure element. Loading can proceed using the pump directly or through the process of charging a high pressure accumulator to provide the fluid volume necessary for single or multiple tests. Actuator displacement rate and applied loading rate can be controlled respectively by pressure compensated-, proportional- and servo-flow controls or volume compensated-, proportional- and servo-pressure controls mounted on a console (Fig. 4). These controls are interchangeable depending on the application. A pilot operated pressure relief valve limits system pressure to that allowable for the rated operation of the various flow and pressure controls.

Actuator loading can be imparted to the beam in either a three- or four-point configuration. Load platens have been designed to prevent localized indentation of the beam surface while its size was optimized as not to induce a significant shear load variation along its contact length.

Applied load is determined using actuator hydraulic pressure or a variety of strain gauge- (Interface 1210) or piezo-electric- (Schaevitz 9051) load cells mounted in the actuator ram. Beam deflection is measured using an AC-linear voltage differential transformer (LVDT) displacement transducer (Schaevitz 500 HCA) (Fig. 5). Load-deflection plots were produced on an X-Y recorder while load and deflection were recorded independently against time on a 2 channel strip chart recorder (Fig. 6). Power was provided to the pump station and the instrumentation package through two portable generators.

Fig. 4 Load/flow control console showing the pressure compensated flow control installed.

Fig. 5 View between the frame load carrying panels illustrating the load cell/platen assembly (left) and the LVDT mounting (right).

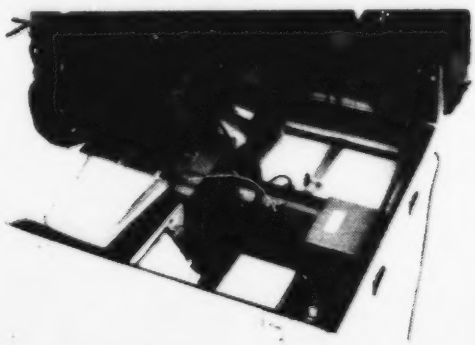

Fig. 6 Signal conditioning and data acquisition systems are shown housed in a heated instrument case.

STUDY SITE AND FIELD METHODOLOGY

"Floral Pond" Saskatchevan, a 35 hectare pond situated 8 km east of Saskatoon, provided the study site. During the winter of 1988/89, the lake site provided an opportunity to examine a cover predominantly characterized by columnar (S2) ice. This ice type, in terms of structural decay, is possibly affected to the greatest extent by radiative acicular melt or "candling". This process creates a "vertically regressive" anisotropic porous structure.

The study plot consisted of a 40 m x 20 m controlled area with energy balance experiments situated at one end while flexural testing and ice cutting took place in the intermediate zone (Fig. 7). Beams were obtained using a combination of power and hand saw techniques in conjunction with a template. The beam breadth was maintained in the range of 0.25-0.30 m. All beam dimensions were of sufficient size in order to minimize crystal size scale effects (Schwarz et al., 1981). Once cut, beams were positioned in an open-water maneuvering area where their breadth and depth were measured and notes taken as to their crystallographic composition and the location of any significant freeze-out flaws, cavities or thermal fissures/cracks which could affect the test results. Once loaded (floated) into the frame and having failed, the specimen fracture surface was examined and notes taken on its geometry and morphology (Fig. 8). Thin sections taken of ice local to the specimen fracture, were analyzed in the laboratory under cross polaroids to determine crystal structure and to gain insight into the free-water content and operative volume of the beam specimen tested.

Fig. 7 Hand-sawn finishing cuts complete the beam specimen cutting procedure.

Fig. 8 Failed beam specimen after removal from test frame. Face shown represents the beam depth with the top surface towards the bottom of the photograph. Note the vertically regressive porous structure.

DISCUSSION

From observations in the field, flexural loading processes leading to failure at the brash-intact ice and the ice-channel boundary interfaces are dominated by brittle behaviour (Fig. 1). For the beam test, a specimen longitudinal strain rate associated with the precipitation of brittle fracture, was calculated and the corresponding applied deflection rate determined. Here the kinematics of beam deformation, warrants the use of elastic beam theory. Its application is appropriate given the physical geometry of the test specimen, the magnitude of deflections observed and the absence of time dependent deformation effects (primarily due to the rate of induced deflection). Deflection rate was maintained (±10%) using the pressure-compensated flow control. In all beam specimens, failure took place within one second. All tests were conducted using 3-point bending load geometry.

Analytical work is currently under way focusing on the interpretation of test results for the radiation-induced structurally decayed ice sheet.

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